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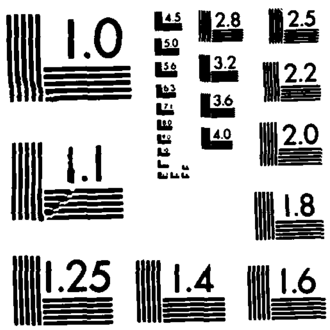

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The Build Policy Study was pursued as a follow-on study to the OMENS (Opportunistic Maintenance Engine Simulator) work. The engine studied is Pratt and Whitney's F100 engine used in the F-15 aircraft. For OMENS details, see Working Paper XRS-81-121.

The OMENS model assumes that whenever you replace a worn or used part, you replace it with a new part. Some life-limited parts, however, have had life-limits extended, been refurbished or salvaged and are still useable. If many like parts with different

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ages are in this category, (i. e., still have useable life left) which one would be the best to install?

At the depot there are occasions where new parts are not available for installation. When this occurs, maintenance personnel may either wait for a new part from supply, or check the pool of used parts to reinstall one as a replacement. The purpose of this Study is to determine which part from a pool of used parts would be the most cost-effective to install, given no new parts are available. Removal rates, NRTS rates, and all available costs studied in OMENS will be considered.

AD 122 868

F100 Engine Build Policy Findings

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November 1982

Working Paper Number XRS-82-217A

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TABLE OF CONTENTS

Abstract

The Build Policy Study was pursued as a follow-on study to the OMENS (Opportunistic Maintenance Engine Simulator) work. The engine studied is Pratt and Whitney's F100 engine used in the F-15 aircraft. For OMENS details, see Working Paper XRS-81-121.

The OMENS model assumes that whenever you replace a worn or used part, you replace it with a new part. Some life-limited parts, however, have had life-limits extended, been refurbished or salvaged and are still useable. If many like parts with different ages are in this category, (i.e., still have useable life left) which one would be the best to install?

At the depot there are occasions where new parts are not available for installation. When this occurs, maintenance personnel may either wait for a new part from supply, or check the pool of used parts to reinstall one as a replacement. The purpose of this Study is to determine which part from a pool of used parts would be the most cost-effective to install, given no new parts are available. Removal rates, NRTS rates, and all available costs studied in OMENS will be considered.

Chapter I. Background and Logic

The Study examines three possibilities in detail. These are (1) always reinstall the oldest part (the one with the least amount of useable life left) in the pool of used parts available (2) always reinstall the youngest part (the one with the most amount of useable life left) in the pool of used parts available, or (3) install a random-aged part from the pool of used parts available.

There were other basic considerations that needed to be dealt with before these three policies were examined. One such consideration was that of screening. If a cost-effective screening policy was already in use on the engine being studied, how could you ever have anything in your pool of used parts that could be used again? If the part had either reached a life limit or been screened out for being "close enough" to its life limit in the first place, should it never be a candidate for reinstallation? This, however, did not take into consideration the possibility that the part was refurbished, salvaged from a FOD (Foreign Object Damage) incident before its life limit was anywhere near being reached, or possibly removed and stored until studies indicated that its life limit could be increased. All of these possibilities could have left different-aged like parts with useable life left in supply.

The second consideration was how to evaluate the "best" build policy. The best would be to adapt the OMENS (Opportunistic Maintenance Engine Simulator) model. This model was already in use to determine screening policies for the F100 engine and all the appropriate costs were already included. These were parts

costs, transportation, pipeline, base and depot maintenance costs as well as removal rates and NRTS rates. All of these areas, then, could easily be statistically analyzed to test for significant differences, depending on which test case was being evaluated. Since the model was already written and developed, the control case of using only new parts was already available. The most effective choice then, was to adapt OMENS to allow for a pool of used parts to be available for installation whenever a life-limited part needed replacement. Instead of replacing the worn part with a new part, a random number generator would "create" a pool of different ages, ranging from (but not including) zero age to the life-limit when new of the part being replaced. Of course, the part cost would also need to be adjusted so that when a used part was reinstalled, it would reflect a cheaper cost than if you had installed a new part. (The cost used was the amount of useable life remaining divided by the life limit times the cost of a new part.)

Another consideration came to light very quickly. One of the optimal policies decided upon at the depot was to screen out anything less than its life limit. So, it became readily apparent that any used part reinstalled at the depot would be the driving part (or pacing part) forcing the next scheduled removal. A re-evaluation of the screening policy was needed. If used parts were going to be reinstalled, they should not have less time left on them than their own depot screen increment. Otherwise, they would always force an engine removal and always force and maintenance action at the depot. (All scheduled removals of life-limited components

on the F100 engine must be done at depot level.) There would be no reason to screen out a part with an 1800 cycle screen that had an 1800 cycle limit and then try to replace it with a "used" part. So, further investigation into a more relaxed screen policy at the depot was undertaken.

Various screening policies were thought through and tested but none seemed to yield quite the same benefits as derived from the "clean-out screens" used at the depot. In other words, if the part was removed at depot, installing any replacement part with less time than a new part did not appear optimal. To decide on some reasonable screens to perform analysis with, original work by Pratt and Whitney was reinvestigated. Their depot screens were in the 300-500 cycle range. The only adverse effect their screens caused was to increase the engine removal rates. This increase was perhaps offset by a decrease in 20-year operating costs as calculated through OMENS.

I chose to do analysis with a modified version of these smaller depot screens because they were values that allowed for reinstallation of used parts, and the screens used were the "best" of the smaller depot screens tested.

Another consideration was that of limiting the use of almost expired parts in the pool of used parts. A random number generator was used to produce 30 (arbitrary) used parts ranging in age from almost zero to almost expired (life-limit almost reached). When testing the policy of reinstallation of the oldest part, it became obvious that this policy would have to be modified. Otherwise, you could quite literally install a part

having only 5 or 10 hours left when drawing from the pool of used parts for a useable part to reinstall.

The first attempt at limiting the minimum allowable age left on a part was to allow only parts that had at least as much time left as their base screens. With this stipulation, however, engine NRTS values were averaging 80-85%! This was entirely out of line and not an acceptable "minimum" policy.

The second attempt at limiting the minimum allowable part life left to be reinstalled was to allow only those parts with at least as much time as their depot screens. This too, however, was not feasible because engine NRTS values came down only to 60-70%.

The third attempt at limiting the reinstallation of nearly expired parts worked quite well and was subsequently added to the model. Each module involved has a driving part (the part that will cause the next scheduled removal of that module) which is life-limited. The model checks through each module to find the part with the smallest amount of time left before the next scheduled part replacement. Then, these parts are coded as drivers, one for each module. The smallest amount of allowable life left on each used part from the pool of used parts must be at least as much as is left on the driver part for the respective module. In other words, never reinstall <u>any</u> used part if it would be the driving part in that module.

The model OMENS was modified to allow a pool of randomly-aged parts to be created each time a life-limited part needed replacement. For the first testing policy, this pool of parts

was sorted from least life left to most life left. Then each random-aged part is checked to see if the life remaining is at least as large as the life left on the driver for that module. The first used part that passes this test is reinstalled and the model continues with the simulation. The cost of the part that is reinstalled is figured like this:

$$\text{Cost of Reinstalled Part} = \text{Cost of New Part} * \frac{\text{Life Left on Used Part}}{\text{Life Limit of New Part}}$$

This equation is in the modified program so that the cost benefits, if any, of using older parts versus new parts could be assessed.

The second test policy investigated sorts the pool of used parts from most life left on the parts to least life left. The part to be reinstalled is the one with the most life left of the random-aged parts from the pool of used parts. It has the most life left before reaching its life limit.

The third test policy investigated simply creates the pool of used parts in the same manner as the other policies, but never sorts the random ages. However, the selection of a part to reinstall is not simply the first randomly-aged part created. The part must also be able to surpass the driving part's age for its respective module. Thus, no random-aged part under this test policy will ever be the driving part causing the next scheduled removal.

There are three cases, then, to be tested and compared to the control case. The control case uses the modified variable depot

screens and installs only new parts as replacements. Each of the three test cases uses all the same data files as the control case and their only differences are as mentioned above.

Each of the cases was then run over a 20-year simulation period and 80 simulations were made per case stuidied.

Because of the amount of data to be analyzed, a computer program was written that would process all of the output data and compute significant differences. This program was written in FORTRAN for use on the CREATE computer system. It can be accessed under user ID LAU/BUILDPOL. The program logic is shown in Chapter IV of this Paper.

Chapter II. Results

Output from the computer model BUILDPOL showed significant differences between the control case and all of the three test cases in the following four categories:

a. Engine removal rate per 1000 flying hours

b. Pipeline cost

c. Parts cost

d. Total 20-year operating cost average

The first significantly lower difference is the engine removal rate per 1000 flying hours. In the control case, it is significantly lower than the other three test cases. This is a very important point to be brought out because it shows that using any of the three cases, other than new parts (the control case) for replacement drives up the engine removal rate significantly. The significance level is .05, meaning that 95% of the time, the numbers tested have significant differences that can be directly attributed to our independent variable, amount of life left on the part to be reinstalled.

Installing used parts, then, with whatever increment of time they have left until life limit is reached, drives up the engine removal rate under all three policies tested.

The second significantly lower difference is the pipeline cost. In the control case, it is significantly lower than the other three test cases. This is a direct reflection of the lower engine removal rate. More depot pipeline support would be necessary

to accommodate the additional engine removals experienced in the three test policies than in the control case.

The third significant difference is the life-limited parts cost. In the control case, it is significantly higher than the other three test cases. This result is logical because parts cost more to replace if new ones are used than if refurbished or older ones are used. As explained earlier in this report, the cost of a reinstalled part was computed as follows:

$$\$\text{Reinstalled Part} = \$\text{Parts (New)} * \frac{\text{Life Left on Reinstalled Part}}{\text{Life Limit of Part (New)}}$$

Therefore, a savings would be expected when using older parts instead of new parts as replacements.

The objective function of the OMENS model averages a life cycle of costs in the following areas: transportation, parts, base maintenance, depot maintenance, and pipeline. These costs are broken out into module and engine costs as well as level of repair (base or depot). A total objective function cost is found by adding these individual costs for the 20-year life cycle. When the total life cycle cost was computed for the control case, it was significantly higher than all the other test cases. This is directly attributed to the high cost of new parts (control case versus used parts in all three test cases). See Table 1.

Table 1

	Control Case 1 (New Parts)	Case 2 (Oldest Parts)	Case 3 (Youngest Parts)	Case 4 (Random Parts)
NRTS%	7.4919	7.8114	7.4376	6.3218
Removals/1000 EFH	7.5214*	7.8155#	8.0790	7.9258
Pipeline($)	144703*	161241	162748	158330
Transportation($)	20883	23428	22703	21869
Parts($)	776867*	709140	696642	703227
Total Cost($)	1032627*	991866	979525	977710
Base Maintenance($)	30568	31499	32554	32309
Depot Maintenance($)	59604	66556	64876	61975
Total Maintenance($)	90172	98055	97430	94284

* Significantly different from other three cases.

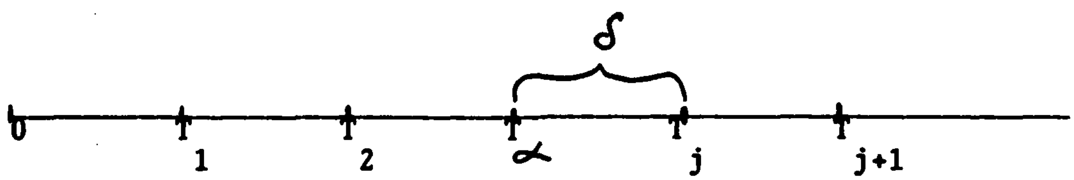
Significantly different from case 3.

At this point, then, it appears that if you can manage the additional pipeline cost and the additional engine removal rate, any of the three test cases could be put into practice. The next step, then, is to see if there are any discrepancies between the three cases.

In reviewing the three test cases, the only significant difference found was the engine removal rate between Case 2 using oldest parts as replacements and Case 3 using youngest parts as replacements. The Case 2 policy of using up the oldest parts produced significantly fewer engine removals than the Case 3 (youngest parts) policy.

It became obvious that all three policies being tested drove engine removals significantly higher because re-used parts were driving removals. Even though re-used parts were tested to make sure they weren't driving the next imminent scheduled event, they were evidently driving scheduled removals further out in time. Because of this another modification was made to the OMENS build policy model. This modification made it impossible for a re-used part to ever drive a removal.

Picture the time line, L, below.



Let T_j = re-used part.

Let T_1 be the most imminent event to occur in the future. Then T_2 is the next event that will occur, and so on.

$$\exists\ T_\alpha : T_1 \leq T_\alpha \leq T_j$$

Let $\delta = T_j - T_\alpha$. Set the depot screen on T_j equal to the depot screen on T_α plus the increment δ. In this way, T_j will never be a driving part causing a depot removal, but the maximum possible life can be used up by allowing T_j to remain in the module as long as the closest future driving part, T_α remains installed.

This new policy was put into effect in all three test cases. Now, in addition to the original idea of not allowing a reinstalled to be the next driver, the reinstalled part is never allowed to force a scheduled removal. Evaluating the three test cases with these changes and comparing results with the control case was done through the BUILDPOL model. The results were that the control case had significantly higher parts costs and 20-year costs than all three test cases. (The parts costs drove the 20-year costs signficantly higher.) See Table 2.

Table 2

	Control Case 1 (New Parts)	Case 2 (Oldest Parts)	Case 3 (Youngest Parts)	Case 4 (Random Parts)
NRTS %	7.4919	5.7794	6.0773	8.2268#
Removals/1000 EFH	7.5214	7.5489	7.6378	7.7450
Pipeline	144,703	142,132	141,568	154,493#
Transportation($)	20,883	20,205	19,330	22,300#
Parts($)	776,867*	741,824	724,890	733,555
Total Cost($)	1,032,627*	992,522	972,090	1,006,737
Base Maintenance($)	30,568	30,889	31,144	31,662
Depot Maintenance($)	59,604	57,470	55,156	64,725#
Total Maintenance($)	90,172	88,359	86,300	96,387#

* Significantly different from the other three cases.

\# Significantly different from the Cases 2 and 3.

Now an evaluation of differences, if any, should be made comparing the three test policies to see if any significant differences exist between them. Table 2 shows that there are no significant differences at the 95% confidence level between using the smallest life left on parts (Case 2) and the largest life left on parts (Case 3).

However, significant differences exist between the random life left (Case 4) and both of the other two test cases (Cases 2 and 3). The engine NRTS % is significantly higher for the random case and the pipeline, transportation, depot and consequently total maintenance costs are also significantly higher for the random case. Evidently, the random part reinstallation policy causes sporadic, less manageable combinations of removals, affecting these areas.

It appears that as long as the random-aged parts policy for building up the modules and engine is not used, NRTS % and removal rates and all objective costs considered but parts costs and consequently total costs have no significant differences between a policy of using only new parts versus used parts. And, you can save a significant amount in parts costs if you use up the re-useable parts instead of all installing only new parts.

Conclusions

Using up the remainder of life left on previously used parts instead of buying new parts can be an effective way to reduce parts costs. Specific guidelines should be followed to avoid significant increases in areas such as engine removal rates, NRTS rates, and objective function costs. These guidelines are:

a. Never reinstall a part that will be a future driver -- change the screen in the manner previously discussed so that the re-used part will be removed/screened coincidental to another life-limited part being removed/screened.

b. Be consistent with your policy -- either always use the largest life left possible or the smallest life left possible -- depleting the pool of parts in a random manner causes significant increases in NRTS and cost areas.

Depleting your pool of used parts from oldest (most life used up) to newest (least life used up) may have an advantage in terms of inventory. There would be less older parts to keep track of because the oldest ones would be depleted faster. This is the only advantage apparent in choosing this oldest part reinstalled policy over the other (youngest part reinstalled).

Either policy practiced with the above guidelines should yield the advantage of cheaper parts costs and cause no adverse effects in terms of engine removals, NRTS %, and any of the examined costs in this Study.

Chapter IV. BUILDPOL Program

```
LIST BUILDPOL

010*#RUN*=(CORE=35K,BCD)#RUNFILE"11";RUNFILE5"12";RUNFILE6"13";RUNFILE7"14"
020 PARAMETER N=80,K=4,L=K-1
030 REAL NRTS(K,N),MNRTS(K),TNRTS(K),VNRTS(K),ZNRTS(L)
040 REAL REMKFH(K,N),MREMKFH(K),TREMKFH(K),VREMKFH(K),ZREMKFH(L)
050 REAL PIPE(K,N),MPIPE(K),TPIPE(K),VPIPE(K),ZPIPE(L)
060 REAL TRANS(K,N),MTRANS(K),TTRANS(K),VTRANS(K),ZTRANS(L)
070 REAL PARTS(K,N),MPARTS(K),TPARTS(K),VPARTS(K),ZPARTS(L)
080 REAL TOTCOST(K,N),MTOTCOST(K),TTOTCOST(K),VTOTCOST(K),ZTOTCOST(L)
090 REAL BSECOST(K,N),MBSECOST(K),TBSECOST(K),VBSECOST(K),ZBSECOST(L)
100 REAL DEPCOST(K,N),MDEPCOST(K),TDEPCOST(K),VDEPCOST(K),ZDEPCOST(L)
110 REAL TOTMNT(K,N),MTOTMNT(K),TTOTMNT(K),VTOTMNT(K),ZTOTMNT(L)
112 CALL FPARAM(1,132)
115 X=FLOAT(N)
120C READ DATA FROM THE FILES
125 DO 2 I=1,K
130 DO 1 J=1,N
140 READ(I+10,20) LN,NRTS(I,J),REMKFH(I,J),PIPE(I,J),TRANS(I,J),
150&PARTS(I,J),TOTCOST(I,J),BSECOST(I,J),DEPCOST(I,J),TOTMNT(I,J)
157 1 CONTINUE
160 2 CONTINUE
170 20 FORMAT(I3,2X,F7.4,2X,F7.4,2X,F7.0,2X,F7.0,2X,F7.0,3X,F8.0,1X,F6.0,
171&3X,F6.0,2X,F7.0)
180C INITIALIZATION
190 DO 5 M=1,K
200 MNRTS(M)=0.0;TNRTS(M)=0.0;VNRTS(M)=0.0
210 MREMKFH(M)=0.0;TREMKFH(M)=0.0;VREMKFH(M)=0.0
220 MPIPE(M)=0.0;TPIPE(M)=0.0;VPIPE(M)=0.0
230 MTRANS(M)=0.0;TTRANS(M)=0.0;VTRANS(M)=0.0
240 MPARTS(M)=0.0;TPARTS(M)=0.0;VPARTS(M)=0.0
250 MTOTCOST(M)=0.0;TTOTCOST(M)=0.0;VTOTCOST(M)=0.0
260 MBSECOST(M)=0.0;TBSECOST(M)=0.0;VBSECOST(M)=0.0
270 MDEPCOST(M)=0.0;TDEPCOST(M)=0.0;VDEPCOST(M)=0.0
280 MTOTMNT(M)=0.0;TTOTMNT(M)=0.0;VTOTMNT(M)=0.0
285 5 CONTINUE
290 DO 6 M=1,K-1
300 ZNRTS(M)=0.0;ZREMKFH(M)=0.0;ZPIPE(M)=0.0;ZTRANS(M)=0.0;ZPARTS(M)=0.0
310 ZTOTCOST(M)=0.0;ZBSECOST(M)=0.0;ZDEPCOST(M)=0.0;ZTOTMNT(M)=0.0
320 6 CONTINUE
330C TOTAL DATA VALUES
340 DO 4 I=1,K
350 DO 3 J=1,N
360 TNRTS(I)=TNRTS(I)+NRTS(I,J)
370 TREMKFH(I)=TREMKFH(I)+REMKFH(I,J)
380 TPIPE(I)=TPIPE(I)+PIPE(I,J)
390 TTRANS(I)=TTRANS(I)+TRANS(I,J)
400 TPARTS(I)=TPARTS(I)+PARTS(I,J)
410 TTOTCOST(I)=TTOTCOST(I)+TOTCOST(I,J)
420 TBSECOST(I)=TBSECOST(I)+BSECOST(I,J)
430 TDEPCOST(I)=TDEPCOST(I)+DEPCOST(I,J)
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```
440 TTOTMNT(I)=TTOTMNT(I)+TOTMNT(I,J)
450 3 CONTINUE
460 4 CONTINUE
470C FIND THE MEANS
480 DO 7 I=1,K
490 MNRTS(I)=TNRTS(I)/(X)
500 MREMKFH(I)=TREMKFH(I)/(X)
510 MPIPE(I)=TPIPE(I)/(X)
520 MTRANS(I)=TTRANS(I)/(X)
530 MPARTS(I)=TPARTS(I)/(X)
540 MTOTCOST(I)=TTOTCOST(I)/(X)
550 MBSECOST(I)=TBSECOST(I)/(X)
560 MDEPCOST(I)=TDEPCOST(I)/(X)
570 MTOTMNT(I)=TTOTMNT(I)/(X)
580 7 CONTINUE
590C FIND THE VARIANCES
600 DO 9 I=1,K
610 DO 8 J=1,N
620 VNRTS(I)=VNRTS(I)+(NRTS(I,J)-MNRTS(I))**2/(X-1)
630 VREMKFH(I)=VREMKFH(I)+(REMKFH(I,J)-MREMKFH(I))**2/(X-1)
640 VPIPE(I)=VPIPE(I)+(PIPE(I,J)-MPIPE(I))**2/(X-1)
650 VTRANS(I)=VTRANS(I)+(TRANS(I,J)-MTRANS(I))**2/(X-1)
660 VPARTS(I)=VPARTS(I)+(PARTS(I,J)-MPARTS(I))**2/(X-1)
670 VTOTCOST(I)=VTOTCOST(I)+(TOTCOST(I,J)-MTOTCOST(I))**2/(X-1)
680 VBSECOST(I)=VBSECOST(I)+(BSECOST(I,J)-MBSECOST(I))**2/(X-1)
690 VDEPCOST(I)=VDEPCOST(I)+(DEPCOST(I,J)-MDEPCOST(I))**2/(X-1)
700 VTOTMNT(I)=VTOTMNT(I)+(TOTMNT(I,J)-MTOTMNT(I))**2/(X-1)
710 8 CONTINUE
720 9 CONTINUE
730C FIND THE Z-SCORES
735 DO 14 M=1,K
740 DO 10 J=1,L
750 ZNRTS(J)=(MNRTS(M)-MNRTS(J+1))/SQRT(VNRTS(M)/(X)+VNRTS(J+1)/(X))
770 ZREMKFH(J)=(MREMKFH(M)-MREMKFH(J+1))/SQRT(VREMKFH(M)/(X)+VREMKFH(J+1)/(X))
790 ZPIPE(J)=(MPIPE(M)-MPIPE(J+1))/SQRT(VPIPE(M)/X+VPIPE(J+1)/X)
800 ZTRANS(J)=(MTRANS(M)-MTRANS(J+1))/SQRT(VTRANS(M)/X+VTRANS(J+1)/X)
810 ZPARTS(J)=(MPARTS(M)-MPARTS(J+1))/SQRT(VPARTS(M)/X+VPARTS(J+1)/X)
820 ZTOTCOST(J)=(MTOTCOST(M)-MTOTCOST(J+1))/SQRT(VTOTCOST(M)/X+VTOTCOST(J+1)/X)
830 ZBSECOST(J)=(MBSECOST(M)-MBSECOST(J+1))/SQRT(VBSECOST(M)/X+VBSECOST(J+1)/X)
840 ZDEPCOST(J)=(MDEPCOST(M)-MDEPCOST(J+1))/SQRT(VDEPCOST(M)/X+VDEPCOST(J+1)/X)
850 ZTOTMNT(J)=(MTOTMNT(M)-MTOTMNT(J+1))/SQRT(VTOTMNT(M)/X+VTOTMNT(J+1)/X)
870C PRINT Z-SCORES FOR ALL THREE CASES AND ALL 10 VARIABLES COMPARED
880C TO THE CONTROL CASE, CASE 1,CASE 2,CASE 3 IN THAT ORDER.
895 PRINT,"CASE",M,"   COMPARED WITH CASE",J+1
896 PRINT," "
900 PRINT,"ZNRTS  = ",ZNRTS(J)
910 PRINT,"ZREMKFH = ",ZREMKFH(J)
920 PRINT,"ZPIPE = ",ZPIPE(J)
930 PRINT,"ZTRANS = ",ZTRANS(J)
940 PRINT,"ZPARTS = ",ZPARTS(J)
950 PRINT,"ZTOTCOST = ",ZTOTCOST(J)
```

```
960 PRINT,"ZBSECOST = ",ZBSECOST(J)
970 PRINT,"ZDEPCOST = ",ZDEPCOST(J)
980 PRINT,"ZTOTMNT = ",ZTOTMNT(J)
985 PRINT," "
990 10 CONTINUE
995 14 CONTINUE
0001000 STOP;END

ready

*BYE
**cost:  $   0.51 to date:  $ 1192.54= |}%
**on at 11.198 - off at 11.269 on  12/01/82
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